Quiescent current of just 3.5 μA and programmable outputs make two regulators (one positive and one negative) the answer to many common small power-supply problems.

CMOS regulators improve battery-powered equipment

A low-drain, voltage-programmable regulator would solve many of the problems associated with the design of power supplies for portable instruments, since system size, weight, operating temperature, cost, and accuracy are all dictated by the battery. Batteries with a flat discharge curve (i.e., "regulated voltage") are the most desirable but also the most expensive. For batteries that depend on a regulator, the choice is no longer between a monolithic regulator with a wastefully high quiescent drain (several milliamperes) and an expensive discrete design with many parts, some not suitable to the task.

Intersil's CMOS IC regulators, the ICL7663 and ICL7664, are programmable positive and negative-voltage regulators for battery-operated equipment. They draw just 3.5-μA quiescent current (with 9 V input; 4 μA with 15 V), but they can regulate up to 40 mA. The low quiescent current reflects the nanoampere operating currents of the reference, amplifier, comparator, and other devices within each regulator.

Although the regulators are complementary, they are not identical. The positive-voltage ICL7663 has a lower output impedance than the negative-voltage ICL7664 at currents above 1 mA and has an additional output terminal (V_{TC}). The lower output impedance of the ICL7663 reflects the additional gain of an npn transistor connected as a voltage follower.

Among the parameters the regulators have in common (besides low I_Q) are a maximum input voltage of 16 V and a reference voltage of 1.3 V (produced by a micropower bandgap which is realized with CMOS, a significant achievement in itself), a line regulation of less than 0.01%/V, a reference

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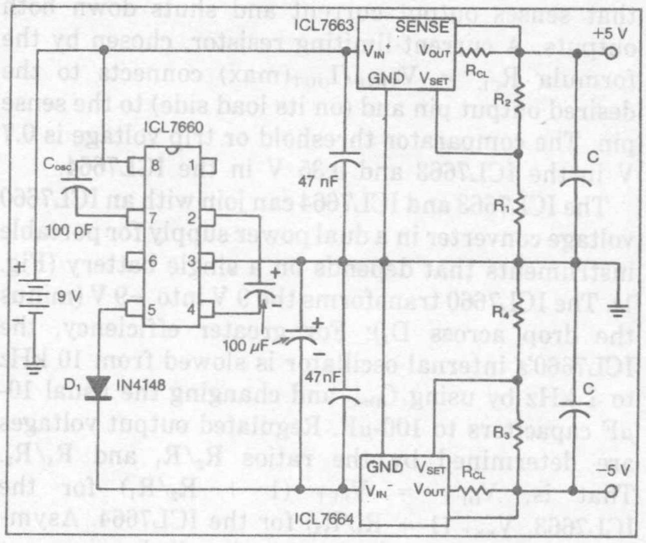
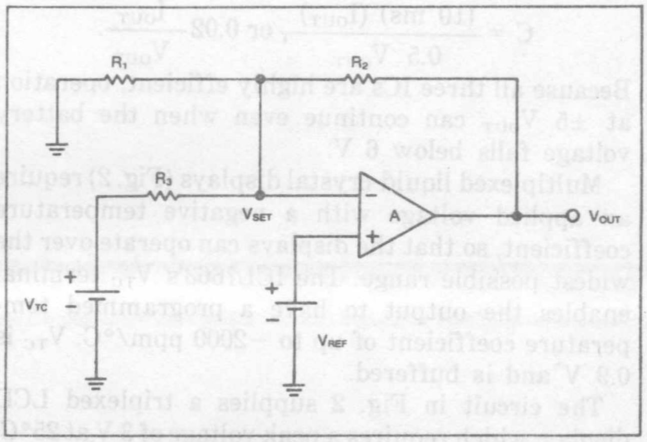


1. A portable instrument can get its positive/negative supply from a single battery with the ICL7663, ICL7664 and ICL7660 voltage converters. Because all three ICs are so efficient, a ±5-V instrument supply will operate even when the battery falls below 6 V.



2. The negative temperature coefficient required by a multiplexed liquid-crystal display is scaled by adjusting the V_{TC} output terminal of an ICL 7663 positive-voltage regulator relative to the V_{SET} input.

temperature coefficient of ±200 ppm/°C, and a dynamic output resistance of 1 Ω at 1 mA.

The output voltage of both regulators can be programmed with just two resistors, which may be high-value and, therefore, low-drain types. Each device has two output pins. The ICL7663 has high and low-current outputs; those of the ICL7664 are equal and are paralleled for higher currents.

For applications like remote data acquisition, which require equipment to turn on when interrogated, a useful feature is the shut-down terminal SHUTDOWN on the ICL7664). The low I_Q allows the system to idle at microamps and then respond to a turn-on logic signal. Unreliable switch contacts are thus eliminated. Both devices feature a comparator that senses output current and shuts down both outputs. A current-limiting resistor, chosen by the formula $R_{CL} = V_{TRIP}/I_{OUT}(max)$ connects to the desired output pin and (on its load side) to the sense pin. The comparator threshold or trip voltage is 0.7 V in the ICL7663 and 0.35 V in the ICL7664.

The ICL7663 and ICL7664 can join with an ICL7660 voltage converter in a dual power supply for portable instruments that depends on a single battery (Fig. 1). The ICL7660 transforms the 9 V into −9 V (minus the drop across D_1): For greater efficiency, the ICL7660's internal oscillator is slowed from 10 kHz to 1 kHz by using C_{OSC} and changing the usual 10-μF capacitors to 100-μF. Regulated output voltages are determined by the ratios R_2/R_1 and R_4/R_3. That is, $V_{OUT} = V_{SET}\ (1 + R_2/R_1)$ for the ICL7663, $V_{SET}\ (1 + R_4/R_3)$ for the ICL7664. Asymmetric output voltages can be handled.

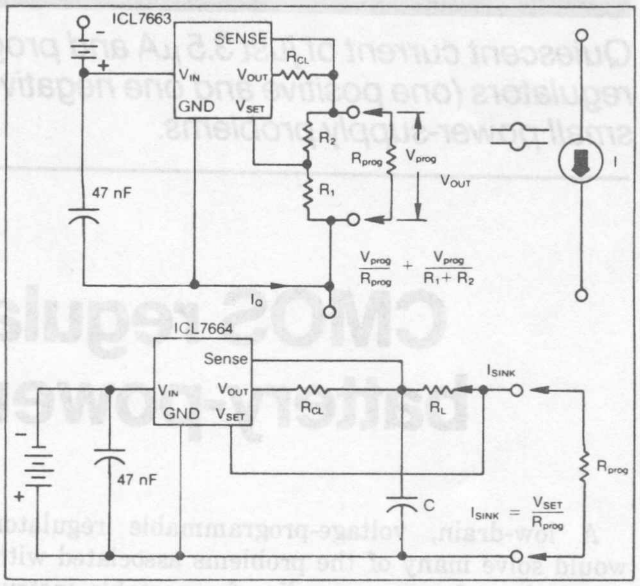
The 47-nF input capacitors prevent possible input instability and they should always be used. A small potential output-overshoot is eliminated by selecting C to reach 50% of the desired V_{OUT} in 10 ms. From the formula $I = C\Delta V/\Delta T$,

$$C = \frac{(10\ \text{ms})\ (I_{OUT})}{0.5\ V_{OUT}},\ \text{or}\ 0.02\frac{I_{OUT}}{V_{OUT}}.$$

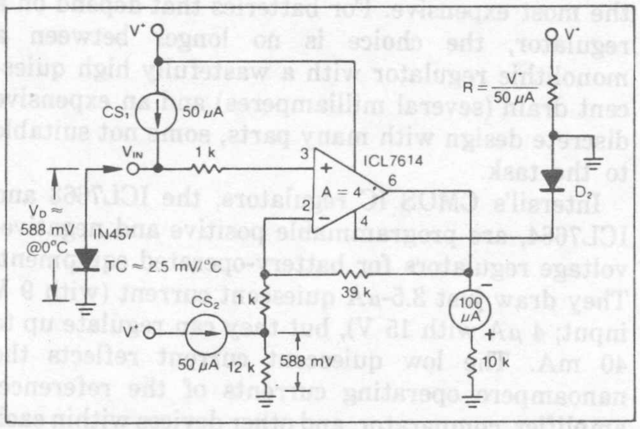
Because all three ICs are highly efficient, operation at ±5 V_{OUT} can continue even when the battery voltage falls below 6 V.

Multiplexed liquid-crystal displays (Fig. 2) require an applied voltage with a negative temperature coefficient, so that the displays can operate over the widest possible range. The ICL7663's V_{TC} terminal enables the output to have a programmed temperature coefficient of up to −2000 ppm/°C. V_{TC} is 0.9 V and is buffered.

The circuit in Fig. 2 supplies a triplexed LCD display, which requires a peak voltage of 3 V at 25°C. This voltage must have a temperature coefficient of −10 mV/°C for operation from −10 to +60°C. The voltage is derived from the ICL7663 by using R_3 to inject V_{TC}, which has a temperature coefficient of



3. With the proper regulator and polarities, the two-terminal current source (top), and the precision current sink (bottom) can serve as either sink or source. In either capacity, however, the bottom circuit can be set more accurately for small currents.



4. In this portable electronic thermometer, a current source (CS_1) based on the ICL7663 sets a constant current for the sensing diode at the given temperature (in this case, 588 μA for 0°C).

+2.5 mV/°C relative to GND or −2.5 mV/°C relative to V_{SET}. R_3 works with R_2 to scale V_{TC} to the correct value:

$$V_{OUT} = V_{SET}\left(1 + \frac{R_2}{R_1}\right) + \frac{R_2}{R_3}(V_{SET} - V_{TC})$$

$$TC\ V_{OUT} = 0 + \frac{R_2}{R_3}(-TC\ V_{TC});\ [TC\ V_{SET} = 0]$$

$$-10\ \text{mV/°C} = \frac{R_2}{R_3}(-2.5\ \text{mV/°C})$$

$$\frac{R_2}{R_3} = 4.$$

When these values are placed into the first equation,

$$3 = 1.3\left(1 + \frac{R_2}{R_1}\right) + 4\ (0.4)$$

$$\frac{R_2}{R_1} = \frac{1}{13}\ .$$

If R_2 is 1 MΩ, R_1 is 13 MΩ, and R_3 is 250 kΩ.

In a two-terminal current source incorporating the ICL7663 (Fig. 3, top), V_{prog} (V_{OUT}) is determined by R_1 and R_2. I_{source} is then V_{prog}/R_{prog} plus I_Q, which is the device quiescent current and the standing current through R_1 and R_2. R_{CL} may be omitted for small currents. A precision sink version (Fig. 3, bottom), based on the ICL7664, may be set more accurately at low currents (less than 20 μA), but the range is restricted for fixed R_L. The source circuit may be used as a sink (substituting an ICL7664) and the sink as a source (substituting an ICL7663), given the correct battery and capacitor polarities.

The two-terminal source replaces a whole boxful of current-limiting diodes, since it can be programmed over a much wider range of currents. In addition, a temperature coefficient of virtually zero is available at every current, instead of just one. The only other programmable monolithic current source available has a temperature coefficient so large that its main use is as a temperature sensor. Even that function can be performed at a lower cost when the ICL7663 serves as a current source (CS_1 and CS_2 in Fig. 4).

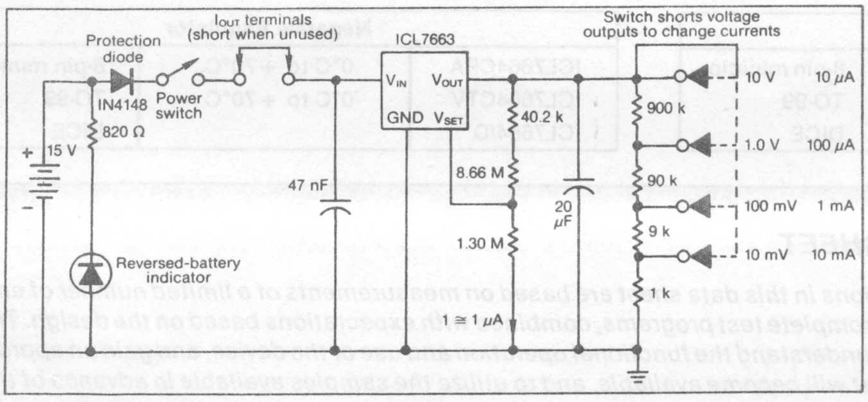
The sensor is either a diode (least expensive) or diode-connected transistor (most predictable). One current source (CS_1) is then adjusted to make V_D, or V_{BE} in the case of a diode-connected transistor, equal to 588 mV at a sensor temperature of 0°C. For any other sensor temperature (T), the formula V_{BE} (mV) = 588 − 2.5 T applies.

If a portable instrument requires constant current, it is usually derived via a resistor from the supply. This approach has two disadvantages. First, the constant current has a finite impedance, and the battery voltage limits the range of available current. Second, the difference between $V_{battery}$ and $V_{operating}$ is wasted across the regulator. In Fig. 4, current sources 1 and 2, as well as the ICL7614 op-amp, can all work down to about 1.5 V. Adding the drop across D_2 means a battery supply as low as 2 V can be used. Therefore, a 9-V battery could theoretically drop to 2 V before operation would cease. Since 5.4 V is the actual end-of-life for such a battery, a better choice for the application is two 1.5-V cells. These cells give 3 V for a much longer period yet occupy the same space. (Use of current sources to extend battery life has never been fully exploited.)

The diode D_2, along with R, divides the supply into positive and negative parts; the diode contributes −0.5 V. This negative part ensures that the meter will deflect downscale for temperatures less than 0°C. The diode can be a Schottky (0.35 V) or germanium (0.27 V) type for less drop. If some zero fuzziness is acceptable, R and D_2 can be omitted.

The ICL7663 can also be designed into a voltage/current calibrator for field use (Fig. 5). Decade ranges are used, but they can easily be changed to 1.999:1 ratios for digital readouts (use 1.900—calibration is tricky at 1.999). Since this circuit has fixed currents and voltages, R_{CL} has been left out to make calibration simpler. If the battery cannot possibly be reversed, then the LED, 820-Ω resistor, and diode may also be omitted.

Because of their wide operating voltage range, the ICL7663 and ICL7664 can be considered programmable zeners, suitable as universal replacement devices. With their low drains, they are well suited to equipment that requires continuous self-calibration.□



5. A portable voltage/current calibrator with fixed currents and voltages: The output sense resistor has been left out of the circuit to make calibration simpler.